

The "True Transformations Relativity" Analysis of the Michelson-Morley Experiment

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Abstract

In this paper we present an invariant formulation of special relativity, i.e., the "true transformations relativity." It deals either with true tensor quantities (when no basis has been introduced) or equivalently with coordinate-based geometric quantities comprising both components and a basis (when some basis has been introduced). It is shown that this invariant formulation, in which special relativity is understood as the theory of a four-dimensional spacetime with the pseudo-Euclidean geometry, completely explains the results of the Michelson-Morley experiment. Two noncovariant approaches to the analysis of the Michelson-Morley experiment are discussed; the conventional one in which only the path lengths (optical or geometrical) are considered, and Driscoll's approach (R.B. Driscoll, *Phys. Essays* **10**, 394 (1997)), in which the increment of phase is determined not only by the segment of geometric path length, but also by the wavelength in that segment. Because these analyses belong to the "apparent transformations relativity," they do not agree with the results of the Michelson-Morley experiment.

Key words: Michelson-Morley experiment, true transformations relativity, apparent transformations relativity

1. INTRODUCTION

Recently Driscoll⁽¹⁾ analyzed the Michelson-Morley⁽²⁾ experiment taking into account, in the calculation of the fringe shift, the Doppler effect on wavelength in the frame in which the interferometer is moving. In contrast to the traditional analysis the non-null fringe shift was found and the author concluded: "that the Maxwell-Einstein electromagnetic equations and special relativity jointly are disproved, not confirmed, by the Michelson-Morley experiment." In this paper we present an invariant approach to special relativity (SR) with tensor quantities (and tensor equations) to the analysis of the Michelson-Morley experiment and find a null fringe shift in agreement with the experiment. We also show why the calculation from⁽¹⁾ leads to the non-null result and why the traditional analysis gives an apparent (not true) agreement with the experiment.

In Sec. 2. we briefly discuss different approaches to SR. In the first approach *SR is formulated in terms of true tensor quantities and true tensor equations*, which we call *the "true transformations (TT) relativity."* That approach is compared with *the usual covariant approach, which mainly deals with the basis components of tensors in a specific, i.e., Einstein's coordinatization*⁽³⁾ of the chosen inertial frame of reference (IFR). The general discussion is illustrated in Sec. 2.1 by two examples: the spacetime length for a moving rod and the spacetime length for a moving clock. The usual, i.e., Einstein's formulation of SR, which is based on his two postulates, and which deals with the Lorentz contraction and the dilatation of time, is also considered in Sec. 2. It is shown that *the Lorentz contraction and the dilatation of time are the apparent transformations (AT)*. (The notions of the TT and the AT are introduced in Ref. 4.) *Any approach to SR which uses the AT we call the "apparent transformations (AT) relativity."* Einstein's formulation of SR obviously belongs to the "AT relativity." The same two examples as mentioned above are considered in the "AT relativity" in Sec. 2.2.

Then in Sec. 3.1 we discuss the nonrelativistic analysis and in Sec. 3.2 the traditional analysis of the Michelson-Morley experiment. In Sec. 3.3 we repeat in short Driscoll's calculation of the fringe shift in the Michelson-Morley experiment. Both, the traditional analysis and Driscoll's analysis of the Michelson-Morley experiment are shown to belong to the "AT relativity." In Sec. 4. we present the analysis of the Michelson-Morley experiment in the "TT relativity" explicitly using two very different synchronizations of distant clocks (they are explained in Sec. 2.) and we find the null result in agreement with the experiment. It is important to note that this result holds

in all permissible coordinatizations since the whole phase of a light wave, the true tensor, $\phi = k^a g_{ab} l^b$ (see Eqs. (21) and (22)) is used in the calculation. In Sec. 4.1 we explain Driscoll's non-null fringe shift as a consequence of an "AT relativity" calculation of the increment of phase. Driscoll's calculation takes into account only a part $k^0 l_0$ of the above mentioned whole phase ϕ and considers that part in two relatively moving IFRs S ($k^0 l_0$) and S' ($k'^0 l'_0$) but only in the Einstein coordinatization (the S frame is the interferometer rest frame). Finally in Sec. 4.2 we explicitly show that the agreement with experiment obtained in the traditional "AT relativity" calculation is actually an apparent agreement. This calculation also deals with the part $k^0 l_0$ of the whole phase ϕ and considers that part in IFRs S and S' but again only in the Einstein coordinatization. In contrast to Driscoll's calculation the traditional analysis considers the contribution $k^0 l_0$ in the interferometer rest frame S , but in the S' frame, in which the interferometer is moving, it considers the contribution $k'^0 l'_0$; the k^0 factor is taken to be the same in S and S' frames. This fact caused an apparent agreement of the traditional analysis with the results of the Michelson-Morley experiment. Since only a part of the whole phase ϕ is considered both results, Driscoll's and the traditional one, are synchronization, i.e., coordinatization, dependent results. Thus the agreement between the traditional analysis and the experiment exists only when Einstein's synchronization of distant clocks is used and not for another synchronization. This is also proved in Sec. 4.2.

2. THE COMPARISON OF THE "TT RELATIVITY" WITH THE USUAL COVARIANT APPROACH AND WITH THE "AT RELATIVITY"

The above mentioned approaches to SR are partly discussed in Refs. 5-8. Rohrlich,⁽⁴⁾ and also Gamba,⁽⁹⁾ emphasized the role of *the concept of sameness of a physical quantity for different observers*. This concept determines the difference between the mentioned approaches and also it determines what is to be understood as a relativistic theory. Our invariant approach to SR, i.e., the "TT relativity," and the concept of sameness of a physical quantity for different observers in that approach, differs not only from the "AT relativity" approach but also from the usual covariant approach (including Refs. 4 and 9).

We first explain the difference between the "TT relativity" and the usual covariant approach to SR. In the "TT relativity" SR is understood as the theory of a four-dimensional (4D) spacetime with pseudo-Euclidean geome-

try. All physical quantities (in the case when no basis has been introduced) are described by *true tensor fields*, that are defined on the 4D spacetime, and that satisfy *true tensor equations* representing physical laws. When the coordinate system has been introduced the physical quantities are mathematically represented by *the coordinate-based geometric quantities* (CBGQs) that satisfy *the coordinate-based geometric equations* (CBGEs). *The CBGQs contain both the components and the basis one-forms and vectors* of the chosen IFR. (Speaking in mathematical language a tensor of type (k,l) is defined as a linear function of k one-forms and l vectors (in old names, k covariant vectors and l contravariant vectors) into the real numbers, see, e.g., Refs. 10-12. If a coordinate system is chosen in some IFR then, in general, any tensor quantity can be reconstructed from its components and from the basis vectors and basis 1-forms of that frame, i.e., it can be written in a coordinate-based geometric language, see, e.g., Ref. 12.) The symmetry transformations for the metric g_{ab} , i.e., the isometries⁽¹⁰⁾, leave the pseudo-Euclidean geometry of 4D spacetime of SR unchanged. At the same time they do not change the true tensor quantities, or equivalently the CBGQs, in physical equations. Thus *isometries* are what Rohrlich⁽⁴⁾ calls *the TT*. In the "TT relativity" different coordinatizations of an IFR are allowed and they are all equivalent in the description of physical phenomena. Particularly two very different coordinatizations, the Einstein ("e")⁽³⁾ and "radio" ("r")⁽¹³⁾ coordinatization, will be briefly exposed and exploited in the paper. In the "e" coordinatization the Einstein synchronization⁽³⁾ of distant clocks and cartesian space coordinates x^i are used in the chosen IFR. The main features of the "r" coordinatization will be given below, see also Refs. 13, 6 and 7. *The CBGQs representing some 4D physical quantity in different relatively moving IFRs, or in different coordinatizations of the chosen IFR, are all mathematically equal since they are connected by the TT (i.e., the isometries)*. Thus they are really the same quantity for different observers, or in different coordinatizations. Hence it is appropriate to call the "TT relativity" approach (which deals with the true tensors or with the CBGQs) as an invariant approach in contrast to the usual covariant approach (which deals with the components of tensors taken in the "e" coordinatization). We suppose that in the "TT relativity" such 4D tensor quantities are well-defined not only mathematically but also *experimentally*, as measurable quantities with real physical meaning. *The complete and well-defined measurement from the "TT relativity" viewpoint is such measurement in which all parts of some 4D quantity are measured.*

However in the usual covariant approach one does not deal with the true

tensors, or equivalently with CBGQs, but with the basis components of tensors (mainly in the "e" coordinatization) and with the equations of physics written out in the component form. Mathematically speaking the concept of a tensor in the usual covariant approach is defined entirely in terms of the transformation properties of its *components* relative to some coordinate system. The definitions of the same quantity in Refs. 4 and 9 also refer to such component form in the "e" coordinatization of tensor quantities and tensor equations. It is true that the components of some tensor refer to the same tensor quantity considered in two relatively moving IFRs S and S' and in the "e" coordinatization, but they cannot be equal, since the bases are not included.

The third approach to SR uses the AT of some quantities. In contrast to the TT the AT are not the transformations of spacetime tensors and they do not refer to the same quantity. Thus they are not isometries and they *refer exclusively to the component form of tensor quantities and in that form they transform only some components of the whole tensor quantity*. In fact, depending on the used AT, only a part of a 4D tensor quantity is transformed by the AT. Such a part of a 4D quantity, when considered in different IFRs (or in different coordinatizations of some IFR) corresponds to different quantities in 4D spacetime. *Some examples of the AT are: the AT of the synchronously defined spatial length,⁽³⁾ i.e., the Lorentz contraction⁽⁴⁻⁹⁾ and the AT of the temporal distance, i.e., the conventional dilatation of time* that is introduced in Ref. 3 and considered in Refs. 7 and 8. *The formulation of SR which uses the AT we call the "AT relativity."* An example of such formulation is *Einstein's formulation of SR which is based on his two postulates and which deals with all the mentioned AT.*

The differences between the "TT relativity," the usual covariant approach and the "AT relativity" will be examined considering some specific examples. First the spacetime lengths, corresponding in "3+1" picture to a moving rod and to a moving clock, will be considered in the "TT relativity." Furthermore the spatial and temporal distances for the same examples will be examined in the "AT relativity." The comparison with the experiments on the Lorentz contraction and the time dilatation is performed in Ref. 8 and it shows that all experiments can be qualitatively and quantitatively explained by the "TT relativity," while some experiments cannot be adequately explained by the "AT relativity." This will be also shown below considering Michelson-Morley experiment.

Before doing this exploration we discuss the notation, different coordina-

tizations and the connections between them. In this paper I use the following convention with regard to indices. Repeated indices imply summation. Latin indices a, b, c, d, \dots are to be read according to the abstract index notation, see Ref. 10 Sec. 2.4; they "...should be viewed as reminders of the number and type of variables the tensor acts on, *not* as basis components." They designate geometric objects in 4D spacetime. Thus, e.g., l_{AB}^a and x_A^a (a distance 4-vector $l_{AB}^a = x_B^a - x_A^a$ between two events A and B whose position 4-vectors are x_A^a and x_B^a) are (1,0) tensors and they are defined independently of any coordinate system. Greek indices run from 0 to 3, while latin indices i, j, k, l, \dots run from 1 to 3, and they both designate the components of some geometric object in some coordinate system, e.g., $x^\mu(x^0, x^i)$ and $x^{\mu'}(x^{0'}, x^{i'})$ are two coordinate representations of the position 4-vector x^a in two different inertial coordinate systems S and S' . Similarly the metric tensor g_{ab} denotes a tensor of type (0,2) (whose Riemann curvature tensor R_{bcd}^a is everywhere vanishing; the spacetime of SR is a flat spacetime, and this definition includes not only the IFRs but also the accelerated frames of reference). This geometric object g_{ab} is represented in the component form in some IFR S , and in the "e" coordinatization, i.e., in the $\{e_\mu\}$ basis, by the 4×4 diagonal matrix of components of g_{ab} , $g_{\mu\nu,e} = \text{diag}(-1, 1, 1, 1)$, and this is usually called the Minkowski metric tensor (the subscript 'e' stands for the Einstein coordinatization).

Different coordinatizations of some reference frame can be obtained using, e.g., different synchronizations. On the other hand different synchronizations are determined by the parameter ε in the relation $t_2 = t_1 + \varepsilon(t_3 - t_1)$, where t_1 and t_3 are the times of departure and arrival, respectively, of the light signal, read by the clock at A , and t_2 is the time of reflection at B , read by the clock at B , that has to be synchronized with the clock at A . In Einstein's synchronization convention $\varepsilon = 1/2$. We can also choose another coordinatization, the "everyday" or "radio" ("r") coordinatization,⁽¹³⁾ which differs from the "e" coordinatization by the different procedure for the synchronization of distant clocks. In the "r" synchronization $\varepsilon = 0$ and thus, in contrast to the "e" synchronization, there is an absolute simultaneity. As explained in Ref. 13: "For if we turn on the radio and set our clock by the standard announcement "...at the sound of the last tone, it will be 12 o'clock", then we have synchronized our clock with the studio clock in a manner that corresponds to taking $\varepsilon = 0$ in $t_2 = t_1 + \varepsilon(t_3 - t_1)$." The "r" synchronization is an assymetric synchronization which leads to an assymetry in the coordinate, one-way, speed of light.⁽¹³⁾ However from the physical point of view the "r"

coordinatization is completely equivalent to the "e" coordinatization. This also holds for all other permissible coordinatizations. Such situation really happens in the "TT relativity." As explained above the "TT relativity" deals with true tensors and the true tensor equations (when no basis has been chosen), or equivalently (when the coordinate basis has been introduced) with the CBGQs and CBGEs. Thus the "TT relativity" deals on the same footing with all possible coordinatizations of the chosen reference frame. As a consequence *the second Einstein postulate referred to the constancy of the coordinate velocity of light, in general, does not hold in the "TT relativity."* Namely, only in Einstein's coordinatization the coordinate, one-way, speed of light is isotropic and constant.

In the following we shall also need the expression for the covariant 4D Lorentz transformations L^a_b , which is independent of the chosen synchronization, i.e., coordinatization of reference frames, see the works.^(14,6,7) It is

$$L^a_b \equiv L^a_b(v) = g^a_b - ((2u^a v_b)/c^2) + (u^a + v^a)(u_b + v_b)/c^2(1 + \gamma), \quad (1)$$

where u^a is the proper velocity 4-vector of a frame S with respect to itself (only $u^0 \neq 0$, see also Ref. 13) $u^a = cn^a$, n^a is the unit 4-vector along the x^0 axis of the frame S , and v^a is the proper velocity 4-vector of S' relative to S . Further $u \cdot v = u^a v_a$ and $\gamma = -u \cdot v/c^2$. When we use the "e" coordinatization then L^a_b is represented by $L^\mu_{\nu,e}$, the usual expression for pure Lorentz transformation, but with v_e^i (the proper velocity 4-vector v_e^μ is $v_e^\mu \equiv dx_e^\mu/d\tau = (\gamma_e c, \gamma_e v_e^i)$, $d\tau \equiv dt_e/\gamma_e$ is the scalar proper-time, and $\gamma_e \equiv (1 - v_e^2/c^2)^{1/2}$) replacing the components of the ordinary velocity 3-vector \mathbf{V} . Obviously, in the usual form, the Lorentz transformations connect two coordinate representations, basis components (in the "e" coordinatization) x_e^μ , $x_e^{\mu'}$ of a given event; x_e^μ , $x_e^{\mu'}$ refer to two relatively moving IFRs (with the Minkowski metric tensors) S and S' ,

$$\begin{aligned} x_e^{\mu'} &= L^{\mu'}_{\nu,e} x_e^\nu, & L^{0'}_{0,e} &= \gamma_e, & L^{0'}_{i,e} &= L^{i'}_{0,e} = -\gamma_e v_e^i/c, \\ L^{i'}_{j,e} &= \delta_j^i + (\gamma_e - 1)v_e^i v_{je}/v_e^2. \end{aligned} \quad (2)$$

Since $g_{\mu\nu,e}$ is a diagonal matrix the space x_e^i and time t_e ($x_e^0 \equiv ct_e$) parts of x_e^μ do have their usual meaning.

The invariant spacetime length (the Lorentz scalar) between two points (events) in 4D spacetime is defined as

$$l = (g_{ab} l^a l^b)^{1/2}, \quad (3)$$

where $l^a(l^b)$ is the distance 4-vector between two events A and B , $l^a = l_{AB}^a = x_B^a - x_A^a$. In the "e" coordinatization the geometrical quantity l^2 can be written in terms of its representation l_e^2 , with the separated spatial and temporal parts, $l^2 = l_e^2 = (l_e^i l_{ie}) - (l_e^0)^2$. Such separation remains valid in other inertial coordinate systems with the Minkowski metric tensor, and in S' one finds $l^2 = l_e'^2 = (l_e'^i l_{i'e}') - (l_e'^0)^2$, where $l_e'^{\mu'}$ in S' is connected with l_e^μ in S by the Lorentz transformation $L^{\mu'}_{\nu,e}(2)$.

This is not so in the "r" coordinatization. In order to explain this statement we now expose the "r" coordinatization in more detail. The basis vectors in the "r" coordinatization are constructed as in Refs. 13, 6 and 7. The temporal basis vector e_0 is the unit vector directed along the world line of the clock at the origin. The spatial basis vectors by definition connect *simultaneous* events, the event "clock at rest at the origin reads 0 time" with the event "clock at rest at unit distance from the origin reads 0 time," and thus they are synchronization-dependent. The spatial basis vector e_i connects two above mentioned simultaneous events when Einstein's synchronization ($\varepsilon = 1/2$) of distant clocks is used. The temporal basis vector r_0 is the same as e_0 . The spatial basis vector r_i connects two above mentioned simultaneous events when "radio" clock synchronization ($\varepsilon = 0$) of distant clocks is used. The spatial basis vectors, e.g., $r_1, r_{1'}, r_{1''}..$ are parallel and directed along an (observer-independent) light line. Hence, two events that are "everyday" ("r") simultaneous in S are also "r" simultaneous for all other IFRs.

The connection between the basis vectors in the "r" and "e" coordinatizations is given^(13,6,7) as

$$r_0 = e_0, \quad r_i = e_0 + e_i.$$

The geometry of the spacetime is generally defined by the metric tensor g_{ab} , which can be expanded in a coordinate basis in terms of its components as $g_{ab} = g_{\mu\nu} dx^\mu \otimes dx^\nu$, and where $dx^\mu \otimes dx^\nu$ is an outer product of the basis 1-forms. The metric tensor g_{ab} becomes $g_{ab} = g_{\mu\nu,r} dx_r^\mu \otimes dx_r^\nu$ in the coordinate-based geometric language and in the "r" coordinatization, where the basis components of the metric tensor are

$$g_{00,r} = g_{0i,r} = g_{i0,r} = g_{ij,r} (i \neq j) = -1, \quad g_{ii,r} = 0.$$

dx_r^μ, dx_r^ν are the basis 1-forms in the "r" coordinatization and in S , and $dx_r^\mu \otimes dx_r^\nu$ is an outer product of the basis 1-forms, i.e., it is the basis for (0,2) tensors (the subscript ' r ' stands for the "r" coordinatization).

The transformation matrix^(6,7) $T_{\nu,r}^\mu$ transforms the "e" coordinatization to the "r" coordinatization. The elements that are different from zero are

$$T_{\mu,r}^\mu = -T_{i,r}^0 = 1.$$

For the sake of completeness we also quote the Lorentz transformation $L^{\mu'}_{\nu,r}$ in the "r" coordinatization. It can be easily found from L^a_b (1) and the known $g_{\mu\nu,r}$, and the elements that are different from zero are

$$\begin{aligned} x_r'^\mu &= L^{\mu'}_{\nu,r} x_r^\nu, \quad L^{0'}_{0,r} = K, \quad L^{0'}_{2,r} = L^{0'}_{3,r} = K - 1, \\ L^{1'}_{0,r} &= L^{1'}_{2,r} = L^{1'}_{3,r} = (-\beta_r/K), \quad L^{1'}_{1,r} = 1/K, \\ L^{2'}_{2,r} &= L^{3'}_{3,r} = 1, \end{aligned} \tag{4}$$

$L^{1'}_{0,r} = L^{1'}_{2,r} = L^{1'}_{3,r} = (-\beta_r/K)$, $L^{1'}_{1,r} = 1/K$, $L^{2'}_{2,r} = L^{3'}_{3,r} = 1$, where $K = (1 + 2\beta_r)^{1/2}$, and $\beta_r = dx_r^1/dx_r^0$ is the velocity of the frame S' as measured by the frame S , $\beta_r = \beta_e/(1 - \beta_e)$ and it ranges as $-1/2 < \beta_r < \infty$. Since $g_{\mu\nu,r}$, in contrast to $g_{\mu\nu,e}$, is not a diagonal matrix, then in the spacetime length l , i.e., l^2 , the spatial and temporal parts are not separated. Expressing l_r^μ in terms of l_e^μ one finds that $l^2 = l_r^2 = l_e^2$, as it must be. It can be easily proved⁽¹³⁾ that the "r" synchronization is an assymetric synchronization which leads to an assymetry in the measured "one-way" velocity of light (for one direction $c_r^+ = \infty$ whereas in the opposite direction $c_r^- = -c/2$). The round trip velocity, however, does not depend on the chosen synchronization procedure, and it is $\equiv c$. Although in the "e" coordinatization the space and time components of the position 4-vector do have their usual meaning, i.e., as in the prerelativistic physics, and in l_e^2 the spatial and temporal parts are separated, it does not mean that the "e" coordinatization does have some advantage relative to other coordinatizations and that the quantities in the "e" coordinatization are more physical.

A symmetry transformation for the metric g_{ab} is called an isometry and it does not change g_{ab} ; if we denote an isometry as Φ^* then $(\Phi^*g)_{ab} = g_{ab}$. Thus an isometry leaves the pseudo-Euclidean geometry of 4D spacetime of SR unchanged. An example of isometry is the covariant 4D Lorentz transformation L^a_b (1). In our terminology *the TT are nothing else but - the isometries*. When the coordinate basis is introduced then, for example, the isometry L^a_b (1) will be expressed as the isometries, the coordinate Lorentz transformation $L^{\mu'}_{\nu,e}$ (2) in the "e" coordinatization, or as $L^{\mu'}_{\nu,r}$ (4) in the "r" coordinatization. In our treatment mainly the coordinate-based geometric

form will be used for tensors representing physical quantities and for tensor equations representing physical laws. The basis components of the CBGQs will be transformed, e.g., by $L^{\mu'}_{\nu,e}$ while the basis vectors e_μ by the inverse transformation $(L^{\mu'}_{\nu,e})^{-1} = L^\mu_{\nu',e}$.

The above consideration enable us to better explain the difference in the concept of *sameness* of a physical quantity for the "TT relativity" approach and the usual covariant approach. We consider a simple example the distance 4-vector (the $(1,0)$ tensor) $l_{AB}^a = x_B^a - x_A^a$ between two events A and B (with the position 4-vectors x_A^a and x_B^a). It can be equivalently represented in the coordinate-based geometric language in different bases, $\{e_\mu\}$ and $\{r_\mu\}$ in an IFR S , and $\{e_{\mu'}\}$ and $\{r_{\mu'}\}$ in a relatively moving IFR S' , as $l_{AB}^a = l_e^\mu e_\mu = l_r^\mu r_\mu = l_e^{\mu'} e_{\mu'} = l_r^{\mu'} r_{\mu'}$, where, e.g., e_μ are the basis 4-vectors, $e_0 = (1, 0, 0, 0)$ and so on, and l_e^μ are the basis components when the "e" coordinatization is chosen in some IFR S . The decompositions $l_e^\mu e_\mu$ and $l_r^\mu r_\mu$ (in an IFR S , and in the "e" and "r" coordinatizations respectively) and $l_e^{\mu'} e_{\mu'}$ and $l_r^{\mu'} r_{\mu'}$ (in a relatively moving IFR S' , and in the "e" and "r" coordinatizations respectively) of the true tensor l_{AB}^a are all mathematically *equal* quantities. Thus they are really the same quantity considered in different relatively moving IFRs and in different coordinatizations. This is the treatment of the distance 4-vector in the "TT relativity." On the other hand the usual covariant approach does not consider the whole tensor quantity, the distance 4-vector l_{AB}^a , but only the basis components, mainly l_e^μ and $l_e^{\mu'}$ in the "e" coordinatization (or⁽⁶⁻⁸⁾ l_r^μ and $l_r^{\mu'}$ in the "r" coordinatization). Note that, in contrast to the above equalities for the CBGQs, the sets of components, e.g., l_e^μ and $l_e^{\mu'}$, taken alone, are not equal, $l_e^\mu \neq l_e^{\mu'}$, and thus they are not the same quantity from the "TT relativity" viewpoint. From the mathematical point of view the components of, e.g., a $(1,0)$ tensor are its values (real numbers) when the basis one-form, for example, e^α , is its argument (see, e.g., Ref. 11). Thus, for example, $l_{AB}^a(e^\alpha) = l_e^\mu e_\mu(e^\alpha) = l_e^\alpha$ (where e^α is the basis one-form in an IFR S and in the "e" coordinatization), while $l_{AB}^a(e^{\alpha'}) = l_e^{\mu'} e_{\mu'}(e^{\alpha'}) = l_e^{\alpha'}$ (where $e^{\alpha'}$ is the basis one-form in S' and in the "e" coordinatization). Obviously l_e^α and $l_e^{\alpha'}$ are not the same real numbers since the basis one-forms e^α and $e^{\alpha'}$ are different bases.

2.1 The TT of the Spacetime Length

In order to explore the difference between the "TT relativity" and the "AT relativity" we consider the spacetime length for a moving rod and then for a moving clock. The same examples will be also examined in the "AT

relativity.” Let us take, for simplicity, to work in 2D spacetime. Then we also take a particular choice for the 4-vector l_{AB}^a . In the usual ”3+1” picture it corresponds to an object, a rod, that is at rest in an IFR S and situated along the common $x_e^1, x_e^{1'}$ – axes; L_0 is its rest length. The decomposition of the geometric quantity l_{AB}^a in the ”e” coordinatization and in S is $l_{AB}^a = l_e^0 e_0 + l_e^1 e_1 = 0e_0 + L_0 e_1$, while in S' , where the rod is moving, it becomes $l_{AB}^a = -\beta_e \gamma_e L_0 e_{0'} + \gamma_e L_0 e_{1'}$, and, as explained above, it holds that

$$l_{AB}^a = 0e_0 + L_0 e_1 = -\beta_e \gamma_e L_0 e_{0'} + \gamma_e L_0 e_{1'}. \quad (5)$$

l_{AB}^a is a tensor of type (1,0) and in (5) it is written in the coordinate-based geometric language in terms of basis vectors $e_0, e_1, (e_{0'}, e_{1'})$ and the basis components $l_e^\mu (l_e^{\mu'})$ of a specific IFR.

We note once again that in the ”TT relativity” the basis components l_e^μ in S and $l_e^{\mu'}$ in S' , when taken alone, do not represent the same 4D quantity. Only the geometric quantity l_{AB}^a , i.e., the CBGQs $l_e^\mu e_\mu = l_e^{\mu'} e_{\mu'}$ comprising both, components and a basis, is the same 4D quantity for different relatively moving IFRs; Ref. 11: ”....the components tell only part of the story. The basis contains the rest of information.” Of course we could equivalently work in another coordinatization, e.g., the ”r” coordinatization, as shown in Refs. 6 and 7. Then we would find that $l_{AB}^a = l_e^\mu e_\mu = l_r^\mu r_\mu = l_e^{\mu'} e_{\mu'} = l_r^{\mu'} r_{\mu'}$, where r_μ and $r_{\mu'}$ are the basis 4-vectors, and l_r^μ and $l_r^{\mu'}$ are the basis components in the ”r” coordinatization, and in S and S' respectively. (The expressions for l_r^μ and $l_r^{\mu'}$ can be easily found from the known transformation matrix $T_{\nu,r}^\mu$.) We see from (5) that in the ”e” coordinatization, which is commonly used in the ”AT relativity,” there is a dilatation of the spatial part $l_e^{1'} = \gamma_e L_0$ with respect to $l_e^1 = L_0$ and not the Lorentz contraction as predicted in the ”AT relativity.” However it is clear from the above discussion that comparison of only spatial parts of the components of the distance 4-vector l_{AB}^a in S and S' is physically meaningless in the ”TT relativity.” When only some components of the whole tensor quantity are taken alone, then, in the ”TT relativity,” they do not represent some definite physical quantity in the 4D spacetime. Also we remark that always the *whole tensor quantity* l_{AB}^a comprising components and a basis is transformed by the Lorentz transformation from S to S' . Note that if $l_e^0 = 0$ then $l_e^{\mu'}$ in any other IFR S' will contain the time component $l_e^{0'} \neq 0$. The spacetime length for the considered case is frame and coordinatization independent quantity $l = (l_{e,r}^\mu l_{\mu e,r})^{1/2} = (l_{e,r}^{\mu'} l_{\mu' e,r})^{1/2} = L_0$. In the ”e” coordinatization and in S , the rest frame of the rod, where the temporal part of l_e^μ is $l_e^0 = 0$, the spacetime length l is a measure of the spatial

distance, i.e., of the rest spatial length of the rod, as in the prerelativistic physics.

In a similar manner we can choose another particular choice for the distance 4-vector l_{AB}^a , which will correspond to the well-known "muon experiment," and which is interpreted in the "AT relativity" in terms of the time dilatation. First we consider this example in the "TT relativity." The distance 4-vector l_{AB}^a will be examined in two relatively moving IFRs S and S' , i.e., in the $\{e_\mu\}$ and $\{e_{\mu'}\}$ bases. The S frame is chosen to be the rest frame of the muon. Two events are considered; the event A represents the creation of the muon and the event B represents its decay after the lifetime τ_0 in S . The position 4-vectors of the events A and B in S are taken to be on the world line of a standard clock that is at rest in the origin of S . The distance 4-vector $l_{AB}^a = x_B^a - x_A^a$ that connects the events A and B is directed along the e_0 basis vector from the event A toward the event B . This geometric quantity can be written in the coordinate-based geometric language. Thus it can be decomposed in two bases $\{e_\mu\}$ and $\{e_{\mu'}\}$ as

$$l_{AB}^a = c\tau_0 e_0 + 0e_1 = \gamma c\tau_0 e_{0'} + \beta_e \gamma_e c\tau_0 e_{1'}. \quad (6)$$

Similarly we can easily find^(6,7) the decompositions of l_{AB}^a in the "r" coordinatization. We again see that these decompositions, containing both the basis components and the basis vectors, are the same geometric quantity l_{AB}^a . l_{AB}^a does have only temporal parts in S , while in the $\{e_{\mu'}\}$ basis l_{AB}^a contains not only the temporal part but also the spatial part. It is visible from (6) that the comparison of only temporal parts of the representations of the distance 4-vector is physically meaningless in the "TT relativity." The spacetime length l is always a well-defined quantity in the "TT relativity" and for this example it is $l = (l_e^\mu l_{\mu e})^{1/2} = (l_e^{\mu'} l_{\mu' e})^{1/2} = (l_r^\mu l_{\mu r})^{1/2} = (l_r^{\mu'} l_{\mu' r})^{1/2} = (-c^2 \tau_0^2)^{1/2}$. Since in S the spatial parts $l_{e,r}^1$ of $l_{e,r}^\mu$ are zero the spacetime length l in S is a measure of the temporal distance, as in the prerelativistic physics; one defines that $c^2 \tau_0^2 = -l_e^\mu l_{\mu e} = -l_r^\mu l_{\mu r}$.

2.2 The AT of the Spatial and Temporal Distances

In order to better explain the difference between the TT and the AT we now consider the same two examples as above but from the point of view of the conventional, i.e., Einstein's⁽³⁾ interpretations of *the spatial length* of the moving rod and *the temporal distance* for the moving clock.

The synchronous definition of *the spatial length*, introduced by Einstein,⁽³⁾ defines length as *the spatial distance* between two spatial points on the (mov-

ing) object measured by simultaneity in the rest frame of the observer. One can see that the concept of sameness of a physical quantity is quite different in the "AT relativity" but in the "TT relativity." Thus for the Einstein definition of *the spatial length* one considers only *the component* $l_e^1 = L_0$ of $l_e^\mu e_\mu$ (when l_e^0 is taken = 0, i.e., the spatial ends of the rod at rest in S are taken simultaneously at $t = 0$) and performs the Lorentz transformation $L^\mu_{\nu,e}$ of the basis components l_e^μ (but not of the basis itself) from S' to S , which yields

$$\begin{aligned} l_e^0 &= \gamma_e l_e^{0'} + \gamma_e \beta_e l_e^{1'} \\ l_e^1 &= \gamma_e l_e^{1'} + \gamma_e \beta_e l_e^{0'}. \end{aligned} \quad (7)$$

Then one retains only the transformation of the spatial component l_e^1 (the second equation in (7)) *neglecting completely the transformation of the temporal part* l_e^0 (the first equation in (7)). Furthermore in the transformation for l_e^1 one takes that the temporal part in S' $l_e^{0'} = 0$, (i.e., the spatial ends of the rod moving in S' are taken simultaneously at some *arbitrary* $t' = b$). The quantity obtained in such a way will be denoted as $L_e^{1'}$ (it is not equal to $l_e^{1'}$ appearing in the transformation equations (7)) This quantity $L_e^{1'}$ defines in the "AT relativity" *the synchronously determined spatial length* of the moving rod in S' . The mentioned procedure gives $l_e^1 = \gamma_e L_e^{1'}$, that is, the famous formula for the Lorentz contraction,

$$L_e^{1'} = l_e^1 / \gamma_e = L_0 / \gamma_e, \quad (8)$$

This quantity, $L_e^{1'} = L_0 / \gamma_e$, is the usual Lorentz contracted *spatial length*, and the quantities L_0 and $L_e^{1'} = L_0 / \gamma_e$ are considered in the "AT relativity" to be *the same quantity* for observers in S and S' . The comparison with the relation (5) clearly shows that the quantities L_0 and $L_e^{1'} = L_0 / \gamma_e$ are *two different and independent quantities in 4D spacetime*. Thus, *in the "TT relativity" the same quantity for different observers is the tensor quantity, the 4-vector* $l_{AB}^a = l_e^\mu e_\mu = l_e^{\mu'} e_{\mu'} = l_r^\mu r_\mu = l_r^{\mu'} r_{\mu'}$; *only one quantity in 4D spacetime*. However *in the "AT relativity" different quantities in 4D spacetime, the spatial distances* $l_e^1 = L_0$ and $L_e^{1'}$ (or similarly in the "r" coordinatization) *are considered as the same quantity for different observers*. The relation for the Lorentz "contraction" of the moving rod in the "r" coordinatization can be easily obtained performing the same procedure as in the "e" coordinatization, and it is

$$L_r^{1'} = L_0 / K = (1 + 2\beta_r)^{-1/2} L_0, \quad (9)$$

see also Refs. 6 and 7. We see from (9) that there is a length "dilatation" $\infty \succ L_r^1 \succ L_0$ for $-1/2 \prec \beta_r \prec 0$ and the standard length "contraction" $L_0 \succ L_r^1 \succ 0$ for positive β_r , which clearly shows that the Lorentz contraction is not physically correctly defined transformation. *Thus the Lorentz contraction is the transformation that connects different quantities (in 4D spacetime) in S and S' , or in different coordinatizations, which implies that it is - an AT.*

The same example of the "muon decay" will be now considered in the "AT relativity" (see also⁽⁷⁾). In the "e" coordinatization the events A and B are again on the world line of a muon that is at rest in S . We shall see once again that the concept of sameness of a physical quantity is quite different in the "AT relativity." Thus for this example one compares *the basis component* $l_e^0 = c\tau_0$ of $l_e^\mu e_\mu$ with the quantity, which is obtained from *the basis component* $l_e^{0'}$ in the following manner; first one performs the Lorentz transformation of the basis components l_e^μ (but not of the basis itself) from the muon rest frame S to the frame S' in which the muon is moving. This procedure yields

$$\begin{aligned} l_e^{0'} &= \gamma_e l_e^0 - \gamma_e \beta_e l_e^1 \\ l_e^{1'} &= \gamma_e l_e^1 - \gamma_e \beta_e l_e^0. \end{aligned} \quad (10)$$

Similarly as in the Lorentz contraction *one now forgets the transformation of the spatial part $l_e^{1'}$* (the second equation in (10)) and considers only the transformation of the temporal part $l_e^{0'}$ (the first equation in (10)). This is, of course, an incorrect step from the "TT relativity" viewpoint. Then taking that $l_e^1 = 0$ (i.e., that $x_{Be}^1 = x_{Ae}^1$) in the equation for $l_e^{0'}$ (the first equation in (10)) one finds the new quantity which will be denoted as $L_e^{0'}$ (it is not the same as $l_e^{0'}$ appearing in the transformation equations (10)). The temporal distance l_e^0 defines in the "AT relativity," and in the "e" basis, the muon lifetime at rest, while $L_e^{0'}$ is considered in the "AT relativity," and in the "e" coordinatization, to define the lifetime of the moving muon in S' . The relation connecting $L_e^{0'}$ with l_e^0 , which is obtained by the above procedure, is then the well-known relation for the time dilatation,

$$L_e^{0'}/c = t'_e = \gamma_e l_e^0/c = \tau_0(1 - \beta_e^2)^{-1/2}. \quad (11)$$

By the same procedure we can find⁽⁷⁾ the relation for the time "dilatation" in the "r" coordinatization

$$L_r^{0'} = K l_r^0 = (1 + 2\beta_r)^{1/2} c\tau_0. \quad (12)$$

This relation shows that the new quantity $L_r^{0'}$, which defines in the "AT relativity" the temporal separation in S' , where the clock is moving, is smaller - time "contraction" - but the temporal separation $l_r^0 = c\tau_0$ in S , where the clock is at rest, for $-1/2 < \beta_r < 0$, and it is larger - time "dilatation" - for $0 < \beta_r < \infty$. From this consideration we conclude that *in the "TT relativity" the same quantity for different observers is the tensor quantity, the 4-vector $l_{AB}^a = l_e^\mu e_\mu = l_e^{\mu'} e_{\mu'} = l_r^\mu r_\mu = l_r^{\mu'} r_{\mu'}$; only one quantity in 4D spacetime.* However *in the "AT relativity" different quantities in 4D spacetime, the temporal distances $l_e^0, L_e^{0'}, l_r^0, L_r^{0'}$ are considered as the same quantity for different observers. This shows that the time "dilatation" is the transformation connecting different quantities (in 4D spacetime) in S and S' , or in different coordinatizations, which implies that it is - an AT.*

We can compare the obtained results for the determination of the space-time length in the "TT relativity" and the determination of the spatial and temporal distances in the "AT relativity" with the existing experiments. This comparison is presented in Ref. 8. It is shown there that the "TT relativity" results agree with all experiments that are complete from the "TT relativity" viewpoint, i.e., in which all parts of the considered tensor quantity are measured in the experiment. However the "AT relativity" results agree only with some of examined experiments.

The difference between the "AT relativity" and the "TT relativity" will be now examined considering the famous Michelson-Morley⁽²⁾ experiment.

3. THE MICHELSON-MORLEY EXPERIMENT

In the Michelson-Morley⁽²⁾ experiment two light beams emitted by one source are sent, by half-silvered mirror O , in orthogonal directions. These partial beams of light traverse the two equal (of the length L) and perpendicular arms OM_1 (perpendicular to the motion) and OM_2 (in the line of motion) of Michelson's interferometer. The behaviour of the interference fringes produced on bringing together these two beams after reflection on the mirrors M_1 and M_2 is examined. The experiment consists of looking for a shift of the interference fringes as the apparatus is rotated. The expected maximum shift in the number of fringes (the measured quantity) on a 90° rotation is

$$\Delta N = \Delta(\phi_2 - \phi_1)/2\pi, \quad (13)$$

where $\Delta(\phi_2 - \phi_1)$ is the change in the phase difference when the interferometer is rotated through 90° . ϕ_1 and ϕ_2 are the phases of waves moving along the

paths OM_1O and OM_2O , respectively.

3.1 The Nonrelativistic Approach

In the nonrelativistic approach the speed of light in the preferred frame is c . Then, on the ether hypothesis, one can determine the speed of light, in the Earth frame, i.e., in the rest frame of the interferometer (the S frame). This speed is $(c^2 - v^2)^{1/2}$ for the path along an arm of the Michelson interferometer oriented perpendicular to its motion. (The motion of the interferometer is at velocity \mathbf{v} relative to the preferred frame (the ether); the Earth together with the interferometer moving with velocity \mathbf{v} through the ether is equivalent to the interferometer at rest with the ether streaming through it with velocity $-\mathbf{v}$.) Since in S both waves are brought together to the same spatial point the phase difference $\phi_2 - \phi_1$ is determined only by the time difference $t_2 - t_1$; $\phi_2 - \phi_1 = 2\pi(t_2 - t_1)/T$, where t_1 and t_2 are the times required for the complete trips OM_1O and OM_2O , respectively, and $T(=\lambda/c)$ is the period of vibration of the light. From the known speed of light one finds that t_1 is $t_1 = t_{OM_1} + t_{M_1O}$, where $t_{OM_1} = L/c(1 - v^2/c^2)^{1/2} = t_{M_1O}$, whence

$$t_1 = 2L/c(1 - v^2/c^2)^{1/2}.$$

(In the following we shall denote that $t_{OM_1} = t_{11}$ and $t_{M_1O} = t_{12}$.) Similarly, the speed of light on the path OM_2 is $c - v$, and on the return path is $c + v$, giving that $t_2 = t_{OM_2} + t_{M_2O} = t_{21} + t_{22} = L/(c - v) + L/(c + v)$. Thence

$$t_2 = 2L/c(1 - v^2/c^2).$$

We see that according to the nonrelativistic approach the time t_1 is a little less than the time t_2 , even though the mirrors M_1 and M_2 are equidistant from O . The time difference $t_2 - t_1$ is

$$t_2 - t_1 = (2L/c)\gamma(\gamma - 1),$$

($\gamma = (1 - v^2/c^2)^{-1/2}$) and to order v^2/c^2 it is $t_2 - t_1 \simeq (L/c)(v^2/c^2)$. The phase difference $\phi_2 - \phi_1$ is determined as $\phi_2 - \phi_1 = \omega(t_{21} + t_{22}) - \omega(t_{11} + t_{12}) = \omega(t_2 - t_1)$ and the change in the phase difference when the interferometer is rotated through 90° is $\Delta(\phi_2 - \phi_1) = 2\omega(t_2 - t_1)$. Inserting it into ΔN (13) ($\omega = 2\pi c/\lambda$, and the measured quantity ΔN is in this case $\Delta N = 2(t_2 - t_1)c/\lambda$) we find that $\Delta N = (4L/\lambda)\gamma(\gamma - 1)$. To the same order v^2/c^2 this ΔN is

$$\Delta N \simeq (2L/\lambda)(v^2/c^2).$$

This result is obtained by the classical analysis in the Earth frame (the interferometer rest frame).

Let us now consider the same experiment in the preferred frame (the S' frame). In the nonrelativistic theory the two frames are connected by the Galilean transformations. Consequently the corresponding times in both frames are equal, $t_1 = t'_1$ and $t_2 = t'_2$, whence $t_2 - t_1 = t'_2 - t'_1$ and, supposing that again the phase difference is determined only by the time difference, $\Delta N' = \Delta N$. However, for the further purposes, it is worth to find explicitly t'_1 and t'_2 considering the experiment directly in the preferred frame. Since the speed of light in the preferred frame is c , the preferred-frame observer considers that the light travels a distance $ct'_{OM'_1}$ along the hypotenuse of a triangle; in the same time $t'_{OM'_1} = t'_{11}$ the mirror M_1 moves to M'_1 , i.e., to the right a distance vt'_{11} . From the right triangle this observer finds $t'_{11} = L/c(1 - v^2/c^2)^{1/2}$. The return trip is again along the hypotenuse of a triangle and the return time $t'_{M'_1O'} = t'_{12}$ is $= t'_{11}$ (the half-silvered mirror O moved to O' in t'_1). The total time for such a zigzag path is, as it must be, $t'_1 = t'_{11} + t'_{12} = t_1$. For the arm oriented parallel to its motion the preferred-frame observer considers that the light, when going from O to M'_2 , must traverse a distance $L + vt'_{OM'_2}$ (we denote $t'_{OM'_2}$ as t'_{21}) at the speed c , whence $L + vt'_{21} = ct'_{21}$ and $t'_{21} = L/(c - v)$. The time $t'_{M'_2O''}$ is denoted as t'_{22} (the half-silvered mirror O moved to O'' in t'_2). Then, in a like manner, the time t'_{22} for the return trip is $t'_{22} = L/(c + v)$. The total time $t'_2 = t'_{21} + t'_{22}$ is, as it must be, equal to t_2 , $t'_2 = t_2$. The phase difference in S' is determined as $\phi'_2 - \phi'_1 = \omega(t'_{21} + t'_{22}) - \omega(t'_{11} + t'_{12}) = \omega(t'_2 - t'_1)$, and it is $\phi'_2 - \phi'_1 = \omega(t_2 - t_1)$. Consequently the expected maximum shift in the number of fringes on a 90° rotation in the S' frame is

$$\Delta N' = \Delta N \simeq (2L/\lambda)(v^2/c^2). \quad (14)$$

It has to be noted here that the same ω , i.e., T , or λ , is used for all paths, both in S and S' . This discussion shows that *the nonrelativistic theory* is a consistent theory giving the same ΔN in both frames. However it *does not agree with the experiment*. Namely Michelson and Morley found from their experiment *that was no observable fringe shift*.

3.2 The Traditional "AT Relativity" Approach

Next we examine the same experiment in the traditional "AT relativity" approach. We remark that the experiment is usually discussed only in the

"e" coordinatization, and again, as in the nonrelativistic theory, the phase difference $\phi_2 - \phi_1$ is considered to be determined only by the time difference $t_2 - t_1$. In the "AT relativity" and in the "e" coordinatization it is postulated (Einstein's second postulate), in contrast to the nonrelativistic theory, that light *always* travels with speed c .

Hence in the S frame (the rest frame of the interferometer), and with the same notation as in the preceding section, we find $t_1 = t_{11} + t_{12} = L/c + L/c = 2L/c$ and also $t_2 = t_{21} + t_{22} = 2L/c = t_1$. With the assumption that only the time difference $t_2 - t_1$ matters, it follows that $\phi_2 - \phi_1 = \omega(t_{21} + t_{22}) - \omega(t_{11} + t_{12}) = \omega(t_2 - t_1) = 0$, whence $\Delta N = 0$, in agreement with the experiment.

In the S' frame (the preferred frame) the time t'_1 is determined in the same way as in the nonrelativistic theory, i.e., supposing that a zigzag path is taken by the light beam in a moving "light clock". Thus, the light-travel time t'_1 is exactly equal to that one in the nonrelativistic theory, $t'_1 = t'_{11} + t'_{12} = 2L/c(1 - v^2/c^2)^{1/2}$. Comparing with $t_1 = 2L/c$ we see that, in contrast to the nonrelativistic theory, it takes a longer time for light to go from end to end in the moving clock but in the stationary clock,

$$t'_1 = t_1/(1 - v^2/c^2)^{1/2} = \gamma t_1. \quad (15)$$

This relation is Eq. (11) for the dilatation of time in the "e" coordinatization that is considered in Sec. 2.2. The presented derivation is the usual way in which it is shown how, in the "AT relativity," the time dilatation is forced upon us by the constancy of the speed of light, see also, e.g., Ref. 15 p.15-6 and Ref. 16 p.359, or an often cited paper on modern tests of special relativity.⁽¹⁷⁾ However, in the "AT relativity," the light-travel time t'_2 is determined by invoking the Lorentz contraction. It is argued that a preferred frame observer measures the length of the arm oriented parallel to its motion to be contracted to a length $L' = L(1 - v^2/c^2)^{1/2}$, Eq. (8) in Sec. 2.2. Then t'_2 is determined in the same way as in the nonrelativistic theory but with L' replacing the rest length L , $t'_2 = t'_{21} + t'_{22} = (L'/(c - v)) + (L'/(c + v))$, i.e.,

$$t'_2 = 2L/c(1 - v^2/c^2)^{1/2} = \gamma t_2 = t'_1. \quad (16)$$

Thence $t'_2 - t'_1 = 0$ and

$$\phi'_2 - \phi'_1 = \omega(t'_{21} + t'_{22}) - \omega(t'_{11} + t'_{12}) = \omega(t'_2 - t'_1) = 0,$$

where again, in the same way as in the nonrelativistic theory, the same ω , i.e., T , or λ , is used for all paths, both in S and S' . As a consequence it is

found in the "AT relativity" that $\Delta N'$ in the S' frame is the same as ΔN in the S frame

$$\Delta N' = \Delta N = 0. \quad (17)$$

We quoted such usual derivation in order to illustrate how the time dilatation and the Lorentz contraction are used in the "AT relativity" to show the agreement between the theory and the famous Michelson-Morley experiment. Although this procedure is generally accepted by the majority of physicists as a correct one and quoted in all textbooks on the subject, we note that such an explanation of the null result of the experiment is very awkward and does not use at all the 4D symmetry of the spacetime. The derivation deals with the temporal and spatial distances as well defined quantities, i.e., in a similar way as in the prerelativistic physics, and then in an artificial way introduces the changes in these distances due to the motion. Our results from Secs. 2., 2.1, and 2.2 reveal why the Lorentz contraction and the time dilatation are not physically correctly defined transformations. Consequently the approach which uses them for the explanation of the experimental results cannot be in agreement with the 4D symmetry of the 4D spacetime.

3.3 Driscoll's "AT Relativity" Approach

In Ref. 1 the above discussed "AT relativity" calculation in the "e" coordinatization (Sec. 3.2) of the fringe shift in the Michelson-Morley experiment is repeated, and, of course, the observed null fringe shift is obtained. This result is independent of changes of \mathbf{v} , the relative velocity of S (the rest frame of the interferometer) and S' (in S' the interferometer is moving), and/or θ , the angle that the undivided ray from the source to the beam divider makes with \mathbf{v} . However, it is noticed⁽¹⁾ that in such a traditional calculation of $\Delta(\phi_2 - \phi_1)$ only path lengths (optical or geometrical), i.e., the temporal distances (for example, the times t_1 and t_2 required for the complete trips OM_1O and OM_2O , respectively), are considered. The Doppler effect on wavelength in the S' frame, in which the interferometer is moving, is not taken into account.

Then the same calculation of $\Delta(\phi'_2 - \phi'_1)$ as the traditional one is performed,⁽¹⁾ but determining the increment of phase along some path, e.g. OM'_1 in S' , not only by the segment of geometric path length (i.e., the temporal distance for that path) but also by the wavelength in that segment (i.e., the frequency of the wave in that segment). Accordingly, the phase difference (in our notation) $\phi'_1 - \phi'_2$, in the S' frame, between the ray along the vertical path

$OM_1'O'$ and that one along the longitudinal path $OM_2'O''$ respectively, is found (see⁽¹⁾) to be

$$\begin{aligned}(\phi'_1 - \phi'_2)_{(b)}/2\pi &= 2(L\nu/c)(1 + \varepsilon + \beta^2) - 2(L\nu/c)(1 + 2\beta^2) \\ &= 2(L\nu/c)(\varepsilon - \beta^2),\end{aligned}\tag{18}$$

Eqs.(23-25) in Ref. 1. L is the length of the segment OM_2 and $\overline{L} = L(1 + \varepsilon)$ ($\varepsilon \ll 1$) is taken in Ref. 1 to be the length of the arm OM_1 . As explained:⁽¹⁾ "The difference $\overline{L} - L = \varepsilon L$ is usually a few wavelengths ($\prec 25$) and is essential for obtaining useful interference fringes." L , \overline{L} and ν are determined in S , the rest frame of the interferometer. In this expression the Doppler effect of \mathbf{v} on the frequencies, *and the Lorentz contraction of the longitudinal arm*, are taken into account. In a like manner Driscoll finds the phase difference in the case when the interferometer is rotated through 90°

$$\begin{aligned}(\phi'_1 - \phi'_2)_{(a)}/2\pi &= 2(L\nu/c)(1 + \varepsilon + 2\beta^2) - 2(L\nu/c)(1 + \beta^2) \\ &= 2(L\nu/c)(\varepsilon + \beta^2),\end{aligned}\tag{19}$$

Eqs.(19-21) in Ref. 1. Hence it is found⁽¹⁾ a "surprising" non-null fringe shift

$$\Delta N' = \Delta(\phi'_2 - \phi'_1)/2\pi = 4(L\nu/c)\beta^2,\tag{20}$$

where $\Delta(\phi'_2 - \phi'_1) = (\phi'_1 - \phi'_2)_{(b)} - (\phi'_1 - \phi'_2)_{(a)}$, and we see that the entire fringe shift is due to the Doppler shift. From the non-null result (20) the author of⁽¹⁾ concluded: "that the Maxwell-Einstein electromagnetic equations and special relativity jointly are disproved, not confirmed, by the Michelson-Morley experiment." However such a conclusion cannot be drawn from the result (20). The origin of the appearance of $\Delta N' \neq 0$ (20) is quite different than that considered in Ref. 1, and it will be explained below. While⁽¹⁾ investigates those changes which are caused by the Doppler effect another work⁽¹⁸⁾ considers the changes in the usual derivation of $\Delta N'$, which are caused by the aberration of light. Both changes are examined only in the "e" coordinatization, and both would be different in, e.g., the "r" coordinatization. This means that $\Delta N'$ in S' will be dependent on the chosen synchronization. Also, both works^(1,18) deal with the Lorentz contraction in the same way as in the traditional analysis. But the Lorentz contraction is an AT, as shown in Secs. 2., 2.1, and 2.2. Consequently, the traditional analysis and the works^(1,18) belong to the "AT relativity," which, as found in Ref. 8, and as follows from the dependence of the theoretical results on the

chosen synchronization, is not capable to explain in a satisfactory manner the results of the Michelson-Morley experiment.

4. THE "TT RELATIVITY" APPROACH

Next we examine the Michelson-Morley experiment from the "TT relativity" viewpoint. The relevant quantity is the phase of a light wave, and it is (when written in the abstract index notation)

$$\phi = k^a g_{ab} l^b, \quad (21)$$

where k^a is the propagation 4-vector, g_{ab} is the metric tensor and l^b is the distance 4-vector. All quantities in (21) are true tensor quantities. As discussed in Sec. 2. these quantities can be written in the coordinate-based geometric language and, e.g., the decompositions of k^a in S and S' and in the "e" and "r" coordinatizations are

$$k^a = k_e^\mu e_\mu = k_e^{\mu'} e_{\mu'} = k_r^\mu r_\mu = k_r^{\mu'} r_{\mu'},$$

where the basis components k^μ of the CBGQ in the "e" coordinatization are transformed by $L^{\mu'}_{\nu,e}$ (2), while the basis vectors e_μ are transformed by the inverse transformation $(L^{\mu'}_{\nu,e})^{-1} = L^\mu_{\nu',e}$. Similarly holds for the "r" coordinatization where the Lorentz transformation $L^{\mu'}_{\nu,r}$ (4) has to be used. By the same reasoning the phase ϕ (21) is given in the coordinate-based geometric language as

$$\phi = k_e^\mu g_{\mu\nu,e} l_e^\nu = k_e^{\mu'} g_{\mu\nu,e} l_e^{\nu'} = k_r^\mu g_{\mu\nu,r} l_r^\nu = k_r^{\mu'} g_{\mu\nu,r} l_r^{\nu'}, \quad (22)$$

(Note that the Lorentz transformation $L^{\mu'}_{\nu,e}$ (2) and also $L^{\mu'}_{\nu,r}$ (4) are the TT, i.e., the isometries, and hence $g_{\mu\nu,e} = g_{\mu'\nu',e}$, $g_{\mu\nu,r} = g_{\mu'\nu',r}$, what is already taken into account in (22).) The traditional derivation of ΔN (Sec. 3.2) deals, as already said, only with the calculation of t_1 and t_2 in S and t'_1 and t'_2 in S' , but does not take into account either the changes in frequencies due to the Doppler effect or the aberration of light. The "AT relativity" calculations^(1,18) improve the traditional procedure taking into account the changes in frequencies,⁽¹⁾ and the aberration of light.⁽¹⁸⁾ But all these approaches explain the experiments using the AT, the Lorentz contraction and the time dilatation, and furthermore they always work only in the "e" coordinatization. None of the "AT relativity" calculations deals with the true tensors or with the CBGQs (comprising both components and a basis). In

this case such 4D tensor quantity is the phase (21) or (22). It will be shown here that the non-null theoretical result obtained in Ref. 1 is a consequence of the fact that Driscoll's calculation also belongs to the "AT relativity" approach. It considers only a part of the 4D tensor quantity ϕ (21), or (22), uses the AT and works only in the "e" coordinatization. *In the "TT relativity" approach to special relativity neither the Doppler effect nor the aberration of light exist separately as well defined physical phenomena. The separate contributions to ϕ (21), or (22), of the ωt (i.e., $k^0 l_0$) factor⁽¹⁾ and $\mathbf{k}\mathbf{l}$ (i.e., $k^i l_i$) factor⁽¹⁸⁾ are, in general case, meaningless in the "TT relativity."* From the "TT relativity" viewpoint only their indivisible unity, the phase ϕ (21), or (22), is a correctly defined 4D quantity. All quantities in (21), i.e., k^a , g_{ab} , l^b and ϕ , are the true tensor quantities, which means that in all relatively moving IFRs and in all permissible coordinatizations always *the same 4D quantity*, e.g., k^a , or l^b , or ϕ , is considered. (Eq. (22) shows it for ϕ .) This is not the case in the "AT relativity" where, for example, the relation $t'_1 = \gamma t_1$ is not the Lorentz transformation of some 4D quantity, and t'_1 and t_1 do not correspond to the same 4D quantity considered in S' and S respectively but to different 4D quantities, as can be clearly seen from Sec. 2.2 (see Eq. (11)). Only in the "e" coordinatization the ωt and $\mathbf{k}\mathbf{l}$ factors can be considered separately. Therefore, and in order to retain the similarity with the prerelativistic and the "AT relativity" considerations, we first determine ϕ (21), (22), in the "e" coordinatization and in the S frame (the rest frame of the interferometer). This means that ϕ will be calculated from (22) as the CBGQ $\phi = k_e^\mu g_{\mu\nu,e} l_e^\nu$.

Let now A , B and A_1 denote the events; the departure of the transverse ray from the half-silvered mirror O , the reflection of this ray on the mirror M_1 and the arrival of this beam of light after the round trip on the half-silvered mirror O , respectively. In the same way we have, for the longitudinal arm of the inteferometer, the corresponding events A , C and A_2 . To simplify the notation we omit the subscript 'e' in all quantities. Then k_{AB}^μ and l_{AB}^μ (the basis components of k_{AB}^a and l_{AB}^a in the "e" coordinatization and in S) for the wave on the trip OM_1 (the events A and B) are $k_{AB}^\mu = (\omega/c, 0, 2\pi/\lambda, 0)$, $l_{AB}^\mu = (ct_{M_1}, 0, \overline{L}, 0)$. For the wave on the return trip M_1O , (the events B and A_1) $k_{BA_1}^\mu = (\omega/c, 0, -2\pi/\lambda, 0)$ and $l_{BA_1}^\mu = (ct_{M_1}, 0, -\overline{L}, 0)$. Hence the increment of phase ϕ_1 for the the round trip OM_1O , is

$$\phi_1 = k_{AB}^\mu l_{\mu AB} + k_{BA_1}^\mu l_{\mu BA_1} = 2(-\omega t_{M_1} + (2\pi/\lambda)\overline{L}), \quad (23)$$

where ω is the angular frequency and, for the sake of comparison with,⁽¹⁾ the

length of the arm OM_1 is taken to be $\bar{L} = L(1 + \varepsilon)$, and L is the length of the segment OM_2 . Using the Lorentz transformation $L^{\mu'}_{\nu,e}$ (2) one can find $k^{\mu'}$ and $l^{\mu'}$ in the "e" coordinatization and in S' for the same trips as in S . Then it can be easily shown that ϕ'_1 in S' is the same as in S , $\phi'_1 = \phi_1$. Also using the transformation matrix $T^\mu_{\nu,r}$ (Sec. 2), which transforms the "e" coordinatization to the "r" coordinatization, one can get all quantities in the "r" coordinatization and in S , and then by the Lorentz transformation $L^{\mu'}_{\nu,r}$ (4) these quantities can be determined in the "r" coordinatization and in S' . ϕ_1 will be always the same in accordance with (22). Note that $g_{\mu\nu,r}$ from Sec. 2 has to be used in the calculation of ϕ in the "r" coordinatization. As an example we quote $k^\mu_{AB,r}$ and $l^\mu_{AB,r}$: $k^\mu_{AB,r} = ((\omega/c) - 2\pi/\lambda, 0, 2\pi/\lambda, 0)$ and $l^\mu_{AB,r} = (ct_{M_1} - \bar{L}, 0, \bar{L}, 0)$. Hence, using $g_{\mu\nu,r}$ one easily finds that

$$\phi_{AB,r} = k^\mu_r g_{\mu\nu,r} l^\nu_r = (-\omega t_{M_1} + (2\pi/\lambda)\bar{L}) = \phi_{AB,e}.$$

For further purposes we shall also need $k^{\mu'}_{AB,r}$ and $l^{\mu'}_{AB,r}$. They are $k^{\mu'}_{AB,r} = ((\gamma\omega/c)(1+\beta) - 2\pi/\lambda, -\beta\gamma\omega/c, 2\pi/\lambda, 0)$ and $l^{\mu'}_{AB,r} = (\gamma ct_{M_1}(1+\beta) - \bar{L}, -\beta\gamma ct_{M_1}, \bar{L}, 0)$ which yields

$$\phi'_{AB,r} = \phi_{AB,r} = \phi'_{AB,e} = \phi_{AB,e}.$$

In a like manner we find k^μ_{AC} and l^μ_{AC} for the wave on the trip OM_2 , (the corresponding events are A and C) as $k^\mu_{AC} = (\omega/c, 2\pi/\lambda, 0, 0)$ and $l^\mu_{AC} = (ct_{M_2}, L, 0, 0)$. For the wave on the return trip M_2O (the corresponding events are C and A_2) $k^\mu_{CA_2} = (\omega/c, -2\pi/\lambda, 0, 0)$ and $l^\mu_{CA_2} = (ct_{M_2}, -L, 0, 0)$, whence

$$\phi_2 = k^\mu_{AC} l_{\mu AC} + k^\mu_{CA_2} l_{\mu CA_2} = 2(-\omega t_{M_2} + (2\pi/\lambda)L). \quad (24)$$

Of course one finds the same ϕ_2 in S and S' and in the "e" and "r" coordinatizations. Hence

$$\phi_1 - \phi_2 = -2\omega(t_{M_1} - t_{M_2}) + 2(2\pi/\lambda)(\bar{L} - L). \quad (25)$$

Particularly for $\bar{L} = L$, and consequently $t_{M_1} = t_{M_2}$, one finds $\phi_1 - \phi_2 = 0$. It can be easily shown that the same difference of phase (25) is obtained in the case when the interferometer is rotated through 90° , whence we find that $\Delta(\phi_1 - \phi_2) = 0$, and $\Delta N = 0$. *According to the construction ϕ (21), or (22), is a frame independent quantity and it also does not depend on the chosen coordinatization in a considered IFR.* Thus we conclude that

$$\Delta N_e = \Delta N'_e = \Delta N_r = \Delta N'_r = 0. \quad (26)$$

This result is in a complete agreement with the Michelson-Morley⁽²⁾ experiment.

4.1 Explanation of Driscoll's Non-Null Fringe Shift

Driscoll's improvement of the traditional "AT relativity" derivation of the fringe shift *can be easily obtained from our "TT relativity" approach taking only the product $k_e^{0'} l_{0'e}$ in the calculation of the increment of phase ϕ_e' in S' in which the apparatus is moving.* All quantities in the "e" coordinatization and in S' are obtained by the Lorentz transformation $L^{\mu'}_{\nu,e}$ (2) from the corresponding ones in S . We remark once again that Driscoll's "AT relativity" approach refers only to the "e" coordinatization (of course it holds for the traditional "AT relativity" approach from Sec. 3.2 as well). Therefore we again omit the subscript 'e' in all quantities. Then we find that in the S' frame $k_{AB}^{\mu'} = (\gamma\omega/c, -\beta\gamma\omega/c, 2\pi/\lambda, 0)$ and $l_{AB}^{\mu'} = (\gamma ct_{M_1}, -\beta\gamma ct_{M_1}, \bar{L}, 0)$, and also $k_{BA_1}^{\mu'} = (\gamma\omega/c, -\beta\gamma\omega/c, -2\pi/\lambda, 0)$ and $l_{BA_1}^{\mu'} = (\gamma ct_{M_1}, -\beta\gamma ct_{M_1}, -\bar{L}, 0)$, giving that

$$(-1/2\pi)(k_{AB}^{0'} l_{0'AB} + k_{BA_1}^{0'} l_{0'BA_1}) = 2\gamma^2 \nu t_{M_1} \simeq 2(L\nu/c)(1 + \varepsilon + \beta^2), \quad (27)$$

which is exactly Driscoll's result ΔP_{Hb} ; for our notation see (18). Similarly one finds that

$$\begin{aligned} (-1/2\pi)(k_{AC}^{0'} l_{0'AC} + k_{CA_2}^{0'} l_{0'CA_2}) &= 2\gamma^2(\nu t_{M_2} + \beta^2 L/\lambda) \\ &\simeq 2(L\nu/c)(1 + 2\beta^2), \end{aligned} \quad (28)$$

which is Driscoll's result $\Delta P_{\Xi b}$, see (18). In the same way we can find in S' Driscoll's result (19) and finally the non-null fringe shift (20).

We remark that the non-null fringe shift (20) would be quite different in another coordinatization, e.g., in the "r" coordinatization, since only a part $k_e^{0'} l_{0'e}$ of the whole 4D tensor quantity ϕ (21) or (22) is considered. The basis components of the metric tensor in the "r" coordinatization, i.e., $g_{\mu\nu,r}$, do not form a diagonal matrix and therefore the temporal and spatial parts of $\phi = k_r^\mu g_{\mu\nu,r} l_r^\nu$ cannot be separated. From the above expressions we can easily show that *the part $k_r^{0'} g_{00,r} l_r^{0'}$ (i.e., $k_r^{0'} l_{0'r}$) is quite different but the Driscoll's expression $k_e^{0'} g_{00,e} l_e^{0'}$ (i.e., $k_e^{0'} l_{0'e}$)*. However the physics must not depend on the chosen coordinatization. Thus when only a part of the whole phase ϕ (21) or (22) is taken into account then it leads to an unphysical result.

The same calculation of $k^i l_i$, the contribution of the spatial parts of $k^{\mu'}$ and $l_{\mu'}$ to $\Delta N_e'$, shows that this term exactly cancel the $k^{0'} l_{0'}$ contribution

(Driscoll's non-null fringe shift (20)), yielding that $\triangle N'_e = \triangle N_e = 0$. Thus the "TT relativity" approach to SR naturally explains the reason for the existence of Driscoll's non-null fringe shift (20).

4.2 Explanation of the "Apparent" Agreement Between the Traditional Analysis and the Experiment

The results of the usual "AT relativity" calculation, which are presented in Sec. 3.2, *can be easily explained from our true tensor formulation of SR taking only the part $k_e^0 l_{0'e}$ of the whole phase ϕ (21) or (22) in the calculation of the increment of phase ϕ'_e in S'* . In contrast to Driscoll's treatment the traditional analysis considers the part $k_e^0 l_{0e}$ (of the whole phase ϕ (21), (22)) in S , the rest frame of the interferometer, and $k_e^0 l_{0'e}$ in S' , in which the apparatus is moving. k_e^0 is not changed in transition from S to S' . Thus the increment of phase ϕ_1 for the round trip OM_1O in S , is

$$\phi_1 = k_{AB}^0 g_{00,e} l_{AB}^0 + k_{BA_1}^0 g_{00,e} l_{BA_1}^0 = -2(\omega/c)(ct_{M_1}) = -2\omega t_{M_1}. \quad (29)$$

In the S' frame we find for the same trip that

$$\phi'_1 = k_{AB}^0 l_{0'AB} + k_{BA_1}^0 l_{0'BA_1} = -2(\omega/c)(\gamma ct_{M_1}) = -2\omega(\gamma t_{M_1}). \quad (30)$$

This is exactly the result obtained in the traditional analysis in Sec. 3.2, which is interpreted as that there is a "time dilatation" $t'_1 = \gamma t_1$. In the same way we find that the increment of phase ϕ_2 for the round trip OM_2O in S , is

$$\phi_2 = k_{AC}^0 l_{0AC} + k_{CA_2}^0 l_{0CA_2} = -2\omega t_{M_2}, \quad (31)$$

and ϕ'_2 in S' is

$$\phi'_2 = k_{AC}^0 l_{0'AC} + k_{CA_2}^0 l_{0'CA_2} = -2(\omega/c)(\gamma ct_{M_2}) = -2\omega(\gamma t_{M_2}). \quad (32)$$

This is again the result of the traditional analysis, the "time dilatation," $t'_2 = \gamma t_2$. For $t_1 = t_2$, i.e., for $\overline{L} = L$, one finally finds the null fringe shift that is obtained in the traditional analysis $\triangle N'_e = \triangle N_e = 0$. We see that *such a null fringe shift is obtained taking into account only a part of the whole phase ϕ (21) or (22), and additionally, in that part, k_e^0 is not changed in transition from S to S'* . Obviously this correct result follows from a physically incorrect treatment the phase ϕ (21) or (22). Furthermore it has to be noted that the usual calculation is always done only in the "e" coordinatization.

Since only the part $k_e^0 l_{0e}$ of the whole phase ϕ (21) or (22) is taken into account (and also $k_e^{0'} = k_e^0$) the results of the usual "AT relativity" calculation are coordinatization dependent. We explicitly show it using the "r" coordinatization.

In the "r" coordinatization the increment of phase ϕ_r is calculated from $\phi_r = k_r^0 g_{00,r} l_r^0$ in S and from $\phi'_r = k_r^0 g_{00,r} l_r^{0'}$ in S' . Hence we find that ϕ_{1r} for the round trip OM_1O in S is

$$\phi_{1r} = -2(\omega t_{M_1} + (2\pi/\lambda)\bar{L}), \quad (33)$$

and ϕ_{2r} for the round trip OM_2O in S is

$$\phi_{2r} = -2(\omega t_{M_2} + (2\pi/\lambda)L). \quad (34)$$

For $\bar{L} = L$, and consequently $t_{M_1} = t_{M_2}$, we find that $\phi_{1r} - \phi_{2r} = 0$, whence $\Delta N_r = 0$. Remark that the phases ϕ_{1r} and ϕ_{2r} differ from the corresponding phases ϕ_{1e} and ϕ_{2e} in the "e" coordinatization. As shown above this is not the case when the whole phase ϕ (21) or (22) is taken into account.

However, in S' , we find for the same trips that

$$\phi'_{1r} = -2(\gamma\omega t_{M_1}(1 + \beta) + (2\pi/\lambda)\bar{L}), \quad (35)$$

$$\phi'_{2r} = -2\gamma^2(1 + \beta^2)(\omega t_{M_2} + (2\pi/\lambda)L). \quad (36)$$

Obviously $\phi'_{1r} - \phi'_{2r} \neq 0$ and consequently it leads to *the non-null fringe shift*

$$\Delta N'_r \neq 0, \quad (37)$$

which holds even in the case when $t_{M_1} = t_{M_2}$. This result clearly shows that the agreement between the usual "AT relativity" calculation and the Michelson-Morley experiment is only an "apparent" agreement. It is achieved by an incorrect procedure and it holds only in the "e" coordinatization. We also remark that the traditional analysis, i.e., the "AT relativity," gives different values for the phases, e.g., ϕ_{1e} , ϕ'_{1e} , ϕ_{1r} and ϕ'_{1r} , since only a part of the whole phase ϕ (21) or (22) is considered. *These phases are frame and coordinatization dependent quantities. When the whole phase ϕ (21) or (22) is taken into account, i.e., in "TT relativity," all the mentioned phases are exactly equal quantities; they are the same, frame and coordinatization independent, quantity.*

5. CONCLUSIONS

In⁽¹⁾ the usual "relativistic" calculation of the fringe shift in the Michelson-Morley experiment is objected on the grounds that it does not take into account the changes in frequencies due to the Doppler effect. Our discussion shows that Driscoll's calculation is not free from ambiguities either. It also does not work with the complete expression for the phase of the light waves ((21) or (22)) travelling along the arms of the Michelson-Morley interferometer. Both calculations are shown to belong to the "AT relativity," which does not deal with the whole 4D tensor quantities and their true transformations. In this paper we have exposed the approach to SR that deals with true tensors and the true tensor equations (when no basis is chosen) or equivalently with the CBGQs and equations (when the coordinate basis is introduced), i.e., the "TT relativity." This approach uses the whole phase ϕ (21) or (22) and yields in all IFRs and in all permissible coordinatizations the observed null fringe shift. At the same time it successfully explains an apparent agreement (it holds only in the "e" coordinatization) of the traditional "AT relativity" approach and disagreement of Driscoll's "AT relativity" approach with the experimental results. They are simply consequences of the use of only some parts of the 4D tensor quantity ϕ (21) or (22) and the use of the AT, the Lorentz contraction and the time dilatation, in the calculation of the increment of phase. The results of the traditional analysis are exactly obtained taking into account only the part $k_e^0 l_{0'e}$ of the whole phase ϕ (21) or (22) in the calculation of the increment of phase ϕ'_e in S' . Similarly the results of Driscoll's analysis are obtained taking only the part $k_e^{0'} l_{0'e}$ in the calculation of ϕ'_e in S' . In conclusion, the analysis performed in this paper reveals that the Michelson-Morley experiment does not confirm either the validity of the traditional Einstein approach or the validity of Driscoll's approach. In other words, the experiment does not confirm the "AT relativity" approach, but rather an invariant "TT relativity" approach to SR.

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